# A Methodology for Assessing the Impact of Radar Transmissions on a Work Zone

Marcelo G. Simas de Oliveira (marcelo.oliveira@ce.gatech.edu), Jonathan Geisheimer (jon.geish@gtri.gatech.edu), Eugene F. Greneker (gene.greneker@gtri.gatech.edu) and John D. Leonard II (john.leonard@ce.gatech.edu)*

ABSTRACT: A new method of speed reduction in work zones is being investigated where an informational safety message is sent to drivers equipped with compatible receivers. The Safety Warning System, a currently available commercial technology, is being used as the test bed system. An experiment was set up within a work zone to detect the presence of vehicles equipped with radar detectors, stimulate them with police radar and a Safety Warning System message, and then observe their responses. Driver responses were measured by using specially modified radar guns, undetectable to vehicles with radar detectors. In this paper, the experimental design, data collection and data analysis methods are discussed along with some preliminary findings.

## INTRODUCTION

The recent growth in the number and magnitude of active work zones in the Nation's highways has increased the interest for technologies and techniques that may reduce vehicle speeds through work zone, with the objective of improving overall work zone safety.

One potential technology for achieving this objective technology is police radar, which has been used in the past as a speed enforcement tool. Radar detectors are devices that can detect the microwave signals produced by police radar. These devices provide motorists of Radar Detector Equipped (RDE) vehicles advance warning of the presence of speed enforcement activity, allowing them to slow down before their speeds can be accurately determined. Motorists' reaction to radar activity constitutes the basis of a well-known speed reduction/safety strategy (1), (2). This strategy is referred to here as *radar transmissions*, or TX, and it can be implemented either through police radar use at selected sites and time or through the deployment of radar transmitters, often called *drones*. The word *drone* means a single tone or a sound that never quits. In this context it means that the radar transmitter broadcasts a continuous wave (CW).

Another type of *radar transmission* (TX) strategy that can be used to affect the traffic stream is the Safety Warning System (SWS), which was developed by a consortium of radar detector manufacturers. SWS is a microwave technique for in-vehicle signing that has been described in previous papers (3), (4). It operates in the Federal Communication Commission (FCC) unlicensed 24.1 GHz band and provides a convenient, off the shelf, commercial technology with which to use for this experiment. The SWS radar system provides a cheap and efficient warning system for drivers. It uses well-established radar technology allowing radar detectors to display over 60 different warning messages.

Typical SWS receivers installed in the approaching driver's vehicle presents a text warning message via an alphanumeric light emitting diode (LED) display, which extends across the back of the receiver. In addition, more advanced receivers have a voice synthesizer that announces the safety warning message to decrease the possibility of driver distraction. Each receiver also issues a warning tone when the signal is first detected which continues until the safety warning message appears on the alphanumeric display. Currently, SWS compliant receivers are being marketed in the United States by Bel-tronics Ltd., Sunkyong America, Inc, Uniden America Corporation, Whistler Corporation, and Cincinnati Microwave.

In addition to the estimated 4,000,000 SWS compliant receivers sold since 1996 capable of receiving and displaying SWS messages, it is estimated that there are 20,000,000 police radar detectors already in use daily on highways in the United States. The SWS transmitter system will cause any of the non-SWS capable radar detectors to alert with the standard police radar warning. The Safety Warning System message can be received and displayed at ranges in excess of 1.5 km separation between transmitter and receiver when line of sight can be maintained. Warning message reception at distances of over 350 meters can be maintained even under worst propagation conditions when the line of sight path between the transmitter and receiver is blocked by the topology of a hill or by trees in the bend of a curve.

---

* Marcelo G. Simas de Oliveira and John D. Leonard II, School of Civil and Environmental Engineering, 790 Atlantic Drive, Georgia Institute of Technology, Atlanta, Georgia 30332, FAX: 404-894-2278. Jonathan Geisheimer and Eugene F. Greneker, Georgia Tech Research Institute, 7220 Richardson Rd., Smyrna, Georgia 30080, FAX: 770-528-7690.

The proper use and deployment of radar speed reduction strategies relies on the availability of estimates of the impacts that it has on individual drivers and the traffic stream in which they travel.

### Prior Methods of Determining Radar Impact on Traffic

Past studies have determined the impacts of radar transmissions on drivers and the traffic stream using before and after speed reduction studies (1), (2). Similar studies were performed as an attempt the asses the efficacy of SWS as a speed reduction strategy (5), (6).

A limitation of these prior studies is that they assume that the reactions of the drivers of RDE Vehicles will translate into changes of the overall traffic stream speed. A previous study (7) conducted by the Authors has shown that the average percentage of RDE vehicles currently 3%. Even if all the radar detector vehicles reduced their speeds, the overall stream's speeds would hardly be affected. The approach of this paper is to examine the individual behavior of RDE vehicles in order to evaluate effectiveness independent of the percentage of RDE vehicles. Once the individual driver behavior is characterized, the results can be extrapolated to effects on the entire traffic stream. A microscopic simulation study conducted by the research team employing some of the data being reported in this paper determined that a significant average speed reduction could be achieved with radar detector densities of 13% and higher (8).

## OBJECTIVE AND SCOPE

This research's objective is to propose a methodology for the qualification and quantification of the reactions of radar detector equipped drivers to radar transmissions. The main objectives of this research can be summarized in the following items:

- Determine the frequency with which radar detector and SWS receiver equipped drivers react to radar transmissions;
- Determine the nature of these reactions;
- Quantify these reactions through changes in vehicle activity (i.e. speed, acceleration, etc.).

The scope of the research was limited to a work zone environment deployment. More specifically, this study deployed and tested an SWS transmitter in a Georgia Department of Transportation (GDOT) work zone. This deployment encompassed the gathering of detailed vehicle activity data, consisting of: radar detector usage, point speeds, speed-time vehicle trajectories and video surveillance.

## IMPLEMENTATION

This section describes the implementation and deployment of the developed radar transmission evaluation method. Initially the study design is presented, followed by the selected study site, then the developed instrumentation setup is presented, and the data reduction process is described.

### Study Design

In order to evaluate the effect of the content of the SWS message being used, the SWS transmitter was also used as a drone radar gun in one of the tested scenarios. A total of three different scenarios were tested during the transmitter deployment. The first scenario featured no transmitter activity. This formed the base scenario against which the remaining two scenarios were compared to. The second scenario featured the transmitter operating in *drone* radar mode (*drone* TX). This way, motorists with radar detectors will react to the transmitter as if it were a K-Band police radar. The third scenario (SWS TX) employed an SWS content-sensitive message (Highway Workers Ahead). Data collection was performed for three workdays for each of the three scenarios, during daylight hours.

### Study Site

The research team selected a section of the STP-190-1 Georgia Department of Transportation (GDOT) Work Zone for the deployment of this study. This section is located on Peachtree Industrial Blvd. and stretches for about 3200 meters south of the intersection with Nelson Brogdon Rd (State Route 20). The reasons that supported the selection of this site were as follows:

- Good line of sight of oncoming traffic;
- Only one lane of traffic per direction;
- Low radar noise interference elements on the work zone.

### Instrumentation

The equipment deployed for this study can be grouped into three stations. The stations along with their components and generated data streams are listed in TABLE 1. The high level flow diagram presented in FIGURE 1 provides an overview of the interactions between the three stations that comprise the experiment. More detailed information on the activities taken at these stations is provided here.

The first station (Road Tube Station) is composed of a set of road tubes connected to a traffic counter/classifier, which in turn is connected to a radio modem. The data generated by the counter/classifier is transmitted through a radio modem down to the Base Station, where it stored in a text file. Also, the crossing of the road tubes by a vehicle triggers a "rolling" time gate on the Base Station. The second station (Base Station) is where the data collection vehicle is located. This station is responsible for most of the data collection and for the monitoring and control of the other two stations through the use of two radio modem links. The main operational loop of this station is works like this: every time a vehicle crosses the loop station the Radar Detector Detector Unit (RDDU) (7) opens a "rolling" time (i.e. it is extended if another vehicle crosses the loops while it is still open) gate of 25 seconds, if the vehicle is determined to have a radar detector then the time of initial detection is noted and a request to start recording radar data and SWS transmission is sent to the Radar Station. In addition, digital pictures of the approaching vehicle are collected and stored in bitmap (BMP) files.

Finally, the third station (Radar Station) is responsible for tracking individual vehicles through the use of two *detuned* radar guns and also for broadcasting *drone* radar and SWS warnings (depending on the scenario being investigated). The detuned radar guns have been modified to transmit outside of the typical police radar band, where radar detectors are unable to detect their presence. The vehicle tracking is performed through the use of two *detuned* police radar guns, which are mounted in an opposing fashion. Each gun's doppler data is recorded as a channel (i.e. channels 1 and 2), with the first one aiming at vehicles as they approach the station and the other one aiming at vehicles as they move away from the station. This station saves the raw binary data generated by the *detuned* radar guns into binary (BIN) files whose filenames were tagged with a time stamp sent by the Base Station.

### Data Collection

Data Collection was done over a period of 3 weeks, with a total of 9 days' worth of data collected. Data collection was done during daylight hours of work weekdays.

### Data Organization and Compilation

The data files containing the data streams collected by the field Stations (listed in TABLE 1) were processed using a set of specially developed tools and archived into relational databases. The developed data translation tools were grouped around the RDDUProc Work Zone Processor Computer program, which was developed in Delphi (9). A MATLAB (10) routine for processing the radar BIN files into spectrogram images was integrated into the RDDUProc program. The data flow of the components involved in the translation of the field data files into the daily databases are displayed in FIGURE 2.

Each of the daily databases consisted of a set of four tables: a tube data table, a radar detector data table, a pictures table and a radar data table. TABLE 2 lists and describes the data elements contained in these tables.

### Data Reduction

This section details the steps involved in reducing the data stored in the daily databases. The steps involved in accomplishing data reduction were built as components of the RDDUProc computer program, which was originally developed for processing the GT RDDU data (7). This program accesses the daily databases described in the previous Section and stores its results into the **Results** database. The **Results** database is composed of four tables, whose data elements are described in TABLE 3.

### Process Overview

The data reduction process involves the following steps:
1. Digitize the vehicle trajectories;
2. Determine the nature of the RDDU data, which can be: positive, false alarm, and noise;
3. Identify which road tube entry matches the vehicle being detected by the RDDU;
4. Determine the best picture frames for the vehicle being detected;
5. Identify the radar trace that corresponds to the vehicle being examined;
6. Attach a brief description of the vehicle along with its vehicle type;

The following sections detail the above listed steps, and provide examples extracted from the generated data set.

*Digitizing Trajectories*

The processed detuned radar data generate complementary spectrogram images, one for each of the recorded channels. These images relate speed (Y-axis) with time (X-axis), a vehicle moving along the monitored stretch of freeway shows up in these images as a dark line. The darkness of the line is proportional to the radar cross section of the object. Therefore, trucks and other large vehicles will show up as darker lines then cars.

The process of transforming these lines in the spectrogram pictures into speed vs. time trajectories is accomplished using a three-step process. These three steps are partially automated through a set of routines of the RDDUProc program (displayed in FIGURE 3), and are as follows:

1. Determine the time when a vehicle crosses the radar station;
2. Digitize points where the slope of the speed vs. time changed;
3. Compute vehicle positions based on digitized speeds and the time when the vehicle crosses the radar station;

The time when the vehicle crosses the radar station can be determined by an abrupt drop in its speed followed by its disappearance on Channel 1, observation of channel 2 at this time shows the reverse phenomenon. This is caused by the rapid change in angle between the radar gun and the approaching vehicle, culminating with zero speed when the angle becomes $90^o$. This point can be visually determined using a slide bar control that overlays the processed images of the two channels.

The next step is done through a heads-up digitizing process, which is done by clicking the mouse at the points where vehicle speed change. The result is a series of speed-time points that connected form a vehicle speed trace. Once this step is completed, a routine of the RDDUProc program uses the time when the vehicle crosses the radar station, whose position is known, to compute the position of the vehicle for each of the digitized points, using a piece-wise integration process.

*Identifying Radar Detector Equipped Vehicles*

The RDDU samples the peaks of energy leakage originating from the radar detectors. Each sampled peak has a power and a frequency value associated with them. These values are plotted in the “RDDU + Pictures” tab of the RDProc program. These plots, coupled with the vehicles’ pictures, allow the identification of radar detector equipped (RDE) vehicles. (4)

## DATA ANALYSIS METHOD

The resulting data generated through the procedures described in the past sections needs further manipulation in order to be turned into usable information on the effects of radar transmissions on RDE vehicles. This generated information includes plots, statistical summaries and statistical tests.

The analysis procedures performed can be grouped in two main groups: Aggregate Vehicle Analysis and Individual Vehicle Analysis. The first one looks at aggregate traffic measures such as average vehicle speeds and accelerations at particular sections of the work zone, the second one actually examines individual vehicle traces and searches for driver reactions to *drone* radar and SWS warnings.

The aggregate analysis was conducted using the measures computed for all the vehicles tracked through the *detuned* radar guns (RDE and non-RDE vehicles). Additionally, extra summary variables were generated for the vehicles identified as RDE. Note that only platoons of vehicles suspected of having at least one RDE vehicle were tracked using the *detuned* radar guns. Additional aggregate measures were collected on all the vehicles that crossed the work zone using the data collected by the tube station.

The analysis of the individual vehicle speed traces was conducted only for those vehicles that were identified as RDE. The vehicle traces related vehicle speed and position in the work zone, changes in speed thought to be attributed to the radar transmissions (*drone* & SWS) were noted and values for vehicle acceleration were computed. The videotapes produced during the data collection were used to complement the information devised from the vehicle speed traces.

In order to automate some of the steps necessary to conducted theses analyses a data analysis protocol was developed and implemented through a set of computer programs and scripts. The following sections describe this framework and its outputs.

## Statistical Analysis

The statistical analysis aims to determine - the behavioral effects of radar transmissions on RDE vehicles. This is done through observation and comparison of the collected field data during the three tested scenarios (No TX, *drone* TX, and SWS TX). The experimental design of the study falls into the Before and After category, with the Before Case being the No transmission scenario and the other two scenarios being the After cases.

The main source of the comparable data is vehicle speed gathered by the *detuned* radar guns, this data can be interpolated into uniformly timed points and be used to compute vehicle acceleration and position. This processed data is the used to compute measures of central tendency and variation, which can be compared through the use of hypothesis testing. The next two sections detail the graphical and quantitative procedures carried out in this data analysis.

## Graphical Analysis of Aggregate Traffic Attributes

The graphs were generated from the results database and the interpolated trajectory points' database. Four types of graph were generated from this database, these were: Speed Cumulative Density Function (CDF) Plots of Speeds at different sections in the monitored work zone, Speed Probability Density Function (PDF) at the same CDF locations, Joint Acceleration and Speed Probability (JASPROD) Plots, and Speed-Distance Probability (SPDISTPROD) Plots.

The first plot type (CDF) allows the determination of the 10 mph pace speed for each of the locations computed. For generating these plots, each data set was first grouped into intervals of five miles per hour (mph). For example, vehicles traveling from 50 mph to 55 mph were grouped together. Frequencies of vehicles traveling in each five-mph group were then obtained and used to calculate the cumulative percentage of vehicles traveling at each interval. The second plot type (PDF) is generated in a similar fashion.

The Joint Acceleration-Speed Probability (JASPROD) Plots displays vehicle activity on the radar monitored part of the work zone. The Joint Acceleration-Speed Probability Density Function (JASPROD) is a three-dimensional (tri-variable) function of speed, acceleration, and the joint probability for a given speed-acceleration bin. An empirical JASPROD is created by sampling the simultaneous speed and acceleration trace of a vehicle along a specified path. Data were divided by homogeneous zones of activity (distance from the radar station location). Dividing the vehicle traces into a matrix of speed and associated accelerations bins is the process through which JASPROD plots are created. Each bin has a unique speed and acceleration range. A JASPROD is shown in FIGURE 4. Once data are binned, the probability of any bin can be calculated by dividing its frequency by the sum of the frequencies of all bins. For each given operational condition that was investigated (no TX, *drone* only TX, and *drone* and SWS TX), the frequency of activity in a specific speed-acceleration bin is the number of seconds of operation in a given bin divided by the total number of seconds of activity. The sum of all frequencies for the vehicle trace will equal one.

The Speed-Distance Probability (SPDISTPROD) Plots are generated in a way similar to the one used to generate the JASPROD Plots, with the two main variables being distance from the tubes in feet (the radar station is located 1300' (442 m) downstream from the road tube station) and the speed in mph. These plots illustrate the distribution of time mean speeds at 100' (34 m) sections of the monitored work zone. An example of a SPDISTPROD plot is shown in FIGURE 5.

## Statistical Summaries and Tests of Aggregate Traffic Attributes

The statistical summary complements the information generated by the graphs explained in the previous section. The variables that were used in the tests were time mean speed and average vehicle acceleration at specific sections of the work zone for the three comparing scenarios. The significance of the changes observed in the monitored variables was assessed using Analysis of Variance (ANOVA).

## Analyses of Individual Vehicle Data

This analysis observes vehicles identified as being equipped with a radar detector (RDE) and searched for changes in vehicle speed that can be attributed to the in-vehicle warning generated by the SWS transmitter. This process involved the plotting of all the RDE vehicles' trajectories in plots such as the one displayed on the second column of FIGURE 6. On this figure a platoon of four vehicles, which includes a RDE vehicle (plotted using the "+" symbol), is depicted, this illustrates the fact that the system is capable of tracking multiple vehicles.

The examination of these speed trajectories attempted to classify the reactions performed by drivers around the location of the radar transmitters into two categories: Ignored (IG) and decelerated (DC). The first category was used for trajectories that showed little or no (less than 2 km/h) decrease in speed on the section of the work zone close to the radar transmitter. The second category was applied to those trajectories that displayed a decrease in vehicle speeds of more than 2 km/h. Additionally, the portions of the trajectories that contained the reduction of speeds were identified and measures of acceleration and speeds were summarized for each of the trajectories identified as belonging to category DC.

## PRELIMINARY RESULTS

Some of the preliminary results obtained from the above described data analysis process are presented in this section. However, the research team is still processing the collected data and will present the full results of this study in a future paper.

### Changes in Traffic Speed

During the whole of data collection time mean speeds were collected at the entrance point of the work zone using pneumatic tubes. These time-mean speeds will be used as a base line for the comparison of the speeds collected around the radar transmitter using the *detuned* radar guns. Comparison of these speeds has showed no significant time mean speed changes that could be attributable to the use of radar transmissions through the work zone.

The non-significance of the difference between TX and non-TX speeds is probably a consequence of the low radar detector densities observed during the study deployment. The average radar detector density observed was found to be less than one percent. Nevertheless, more detailed examination of the collected data is being conducted as an attempt to better understand the observed speed changes.

The examination of the JASPROD plots also did not reveal a dramatic trend towards lower speeds or decelerations. However, the SPDISTPROD plots for the TX scenarios reveal a trend towards lower vehicle speeds downstream of the radar station, demonstrating that some vehicles did reduce their speeds as they were confronted with *drone* radar and SWS transmissions.

### Quantified Driver Reactions

The observation of speed trajectories, from vehicles that were identified as RDE, showed that a higher percentage of vehicles reacted through deceleration (DC) than through ignoring (IG) when the SWS message was being broadcasted, compared to the two initial scenarios (no TX and *drone* TX). This compares positively with *drone* radar transmissions, which yielded roughly equal percentages of DC and IG reactions. For no radar transmissions the majority of vehicle trajectories displayed IG reactions. These percentages, along with the average deceleration rates observed by the DC vehicles, are summarized in TABLE 4.

## SUMMARY AND FINAL COMMENTS

A new procedure for the monitoring of driver reactions to radar transmissions was developed and presented. Custom software was developed to control the system and process the generated data streams. Detailed descriptions of the procedures implemented in this software are provided, they can be implemented using off-the-shelf development tools. The developed methodology was applied to test the effects of radar transmissions (*drone* and SWS) on drivers as they traveled through a work zone.

The preliminary analysis conducted on the aggregate speed data collected does not show significant speed changes that could be attributable to the use of radar transmissions. However, the researchers believe that this is a consequence of the low radar detector densities (less than one percent) observed at the site. On the other hand, examination of the individual vehicle data collected supports that radar transmissions cause the majority of the vehicles equipped with radar detectors to reduce their speeds. Different types of reaction to *drone* and SWS were also obtained from the examination of individual speed data, with a bigger proportion of the RDE vehicles decelerating when compared to the *drone* and no TX scenarios.

The procedure for obtaining vehicle traces presented here has potential applications on other fields of transportation research. It allows the collection of high-resolution multiple vehicle activity data that can be used for other applications such as: car-following model calibration, reaction time studies, air-quality vehicle activity modeling, etc. Moreover, the ability of discerning RDE vehicles makes the practical implications of the application of this methodology very important. This is because the methodology makes it is possible to quantify individual driver reactions, as well as their impact on other vehicles.

## ACKNOWLEDGEMENTS

This work was conducted using data acquired under sponsorship of the United States Department of Transportation (USDOT) contract DTFH61-98-X-001100. The authors wish to express their gratitude to the USDOT and the Georgia Department of Transportation (GDOT) for their cooperation. The views presented in this paper are those of

the authors and do not necessarily represent those of the United States Government, USDOT, State of Georgia, or GDOT.

**REFERENCES**

1. Pigman, Jerry G., et al. Evaluation on Unmanned Radar Installations. In Transportation Research Record 1244, TRB, Washington, D.C., 1989, pp. 7-16.
2. Benekohal, Rahin F., et al. Temporal Speed Reduction Effects of Drone Radar in Work Zone. In *Transportation Research Record 1409*, TRB, Washington, D.C., 1993, pp. 32-41.
3. Greneker, E. F., "In-vehicle Signing System," Society for Optical Engineering's Photonics East 96 Symposium, Boston, November 1996.
4. Greneker, E. F., Geisheimer, J. L., Rausch, E. O., "Farm equipment collision avoidance using only homodyne radar," *Proceedings of SPIE*, vol. 4033, pp. 23-32, AeroSense '2000, Orlando, Florida, April 2000.
5. Bowlds, D, Willis, K., Roadifer, L., Meyer, E., Safety Warning System Kansas Deployment Evaluation Report, Midwest States Smart Work Zone Deployment Initiative, 2001.
6. Safety Warning System Iowa Deployment Evaluation Report, Midwest States Smart Work Zone Deployment Initiative, 2001.
7. Oliveira, M.G.S, Leonard, J.D., Geisheimer, J., Greneker, E., A Study of Radar Detector Usage on Georgia Highways. Presented at the 80th TRB Annual Meeting, Washington, D.C., 2001.
8. Oliveira, M.G.S, Leonard, J.D, Geisheimer, J., Greneker, E.F., Microscopic Simulation of a SWS Deployment in a Work Zone – Preliminary Evaluation Report, School of Civil and Environmental Engineering, Georgia Institute of Technology, Atlanta, GA, 2001.
9. Borland, "Delphi Version 5.0 – User Manual", Borland Corporation, 1999.
10. Mathworks, Using Matlab – Version 5.3 Release 11, The Math Works Inc., Natick, MA, 1999.
11. Statgraphics Plus 4.0 - User Manual, Magnugistics, Rockville, MD, 1999.

**LIST OF TABLES**

**TABLE 1 Data collection stations their components and data streams.**

| *Station #* | *Station Name* | *Components* | *Data Streams* |
|---|---|---|---|
| 1 | Road Tubes Station | • Road Tubes;<br>• Classifier;<br>• Radio Modem; | • Tube Data Text Strings (transmitted to the Base Station) |
| 2 | Base Station | • Radar Detector Detector Unit (RDDU);<br>• Digital Camera;<br>• Main Laptop;<br>• Video Camera;<br>• Radio Modems (one for each of the other two stations; | • Tube Text File;<br>• RDDU Text File;<br>• Picture Bitmaps;<br>• Video Tapes; |
| 3 | Radar Station | • *Detuned* Radar Guns;<br>• SWS Transmitter;<br>• Second Laptop;<br>• Radio Modem; | • Raw *Detuned* Radar Binary (BIN) Files; |

**TABLE 2 Daily database tables their data elements and descriptions.**

| *Table Name* | *Data Elements* | |
|---|---|---|
| Tube Data Table | • TIME | Base Station Time Tag |
| | • DIRECTION | Direction of vehicle |
| | • VEHNUMBER | Vehicle Number Since Start of Study |
| | • SPEED | Speed in mph |
| | • NBAXLES | Number of Axles |
| Radar Detector Data Table | • TIME | Base Station Time Tag |
| | • FREQUENCY | Frequency of Detected LO |
| | • POWER | Power of Detected LO |
| Picture Table | • TIME | Base Station Time Tag |
| | • PICTURE | JPEG Compressed Binary Picture Data |
| Radar Data Table | • TIME | Base Station Time Tag |
| | • RADAR_DATA | Zip Compressed *Detuned* Radar Data |
| | • PROC1 | Flag, True if Channel 1 is processed |
| | • CHANNEL1 | JPEG Spectrogram Image of Channel 1 |
| | • PROC2 | Flag, True if Channel 1 is processed |
| | • CHANNEL2 | JPEG Spectrogram Image of Channel 2 |
| | • FSTART | Start Frequency used for Processing Channels |
| | • FSTOP | Stop Frequency used for Processing Channels |
| | • FFTS | FFT Size used for Processing Channels |

**TABLE 3 Results database tables their data elements and descriptions.**

| *Table Name* | *Data Elements* | |
|---|---|---|
| Results | • STARTTIME | Start Time of the Detection Window |
| | • ENDTIME | Start Time of the Detection Window |
| | • DET_TYPE | Detection Type (i.e. Positive, False Alarm, etc.) |
| | • VEHTYPE | Type of Vehicle (i.e. Passenger Car, Truck, etc.) |
| | • TUBETIME | Base Station Time when Vehicle crossed the Tube Station |
| | • RADARTIME | Base Station Time Tag of the *Detuned* Radar Data |
| | • TRAJ_ID | Trajectory Key of the Vehicle |
| | • COMMENTS | User Comments |
| Trajectories | • TRAJ_ID | Trajectory Key Field |
| | • NBPOINTS | Number of Digitized Points |
| | • COMMENTS | User Comments |
| Trajectory Points | • TRAJ_ID | Trajectory Key Field |
| | • TIME | Base Station Time of the Point |
| | • FREQUENCY | Base Station Time of the Point |
| | • SPEED | Speed of the Point in mph |
| | • POSITION | Position of Point Relative to the Tube Station |
| | • ACCELERATION | Acceleration of the Point in mph/sec |
| Tube Results | • TIME | Base Station Time Tag |
| | • DIRECTION | Direction of vehicle |
| | • VEHNUMBER | Vehicle Number Since Start of Study |
| | • SPEED | Speed in mph |
| | • NBAXLES | Number of Axles |

**TABLE 4 Summary of speed trajectory analysis.**

| **Scenario** | **% IG** | **% DC** | **Avg Deceleration of DC [m/s$^2$]** |
|---|---|---|---|
| No TX | 66 | 34 | -0.26 |
| *Drone* TX | 45 | 55 | -0.31 |
| SWS TX | 29 | 71 | -0.22 |

**LIST OF FIGURES**

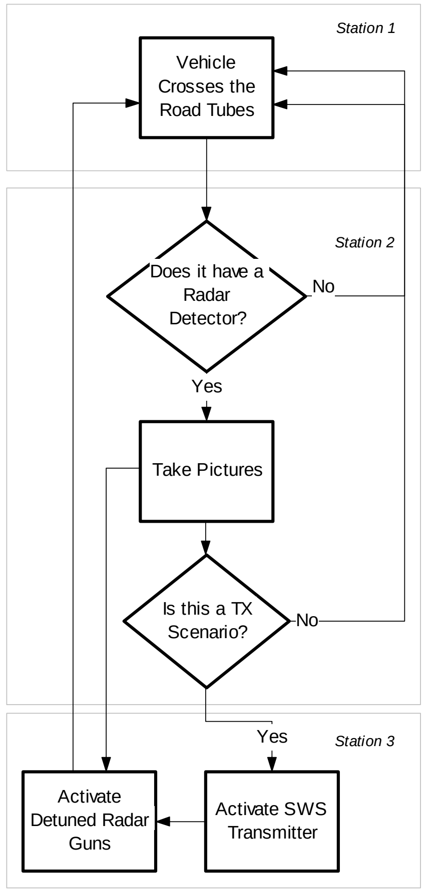



**FIGURE 1 High Level Flow Diagram of the Experiment.**

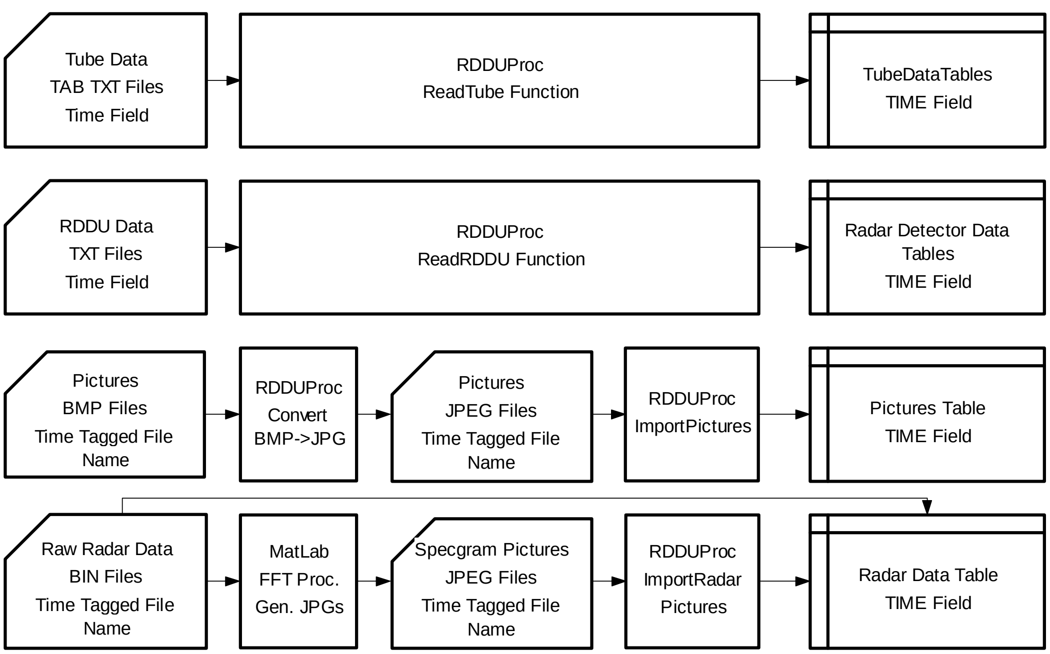



**FIGURE 2 Data Streams and their flow into the Database Tables.**

I

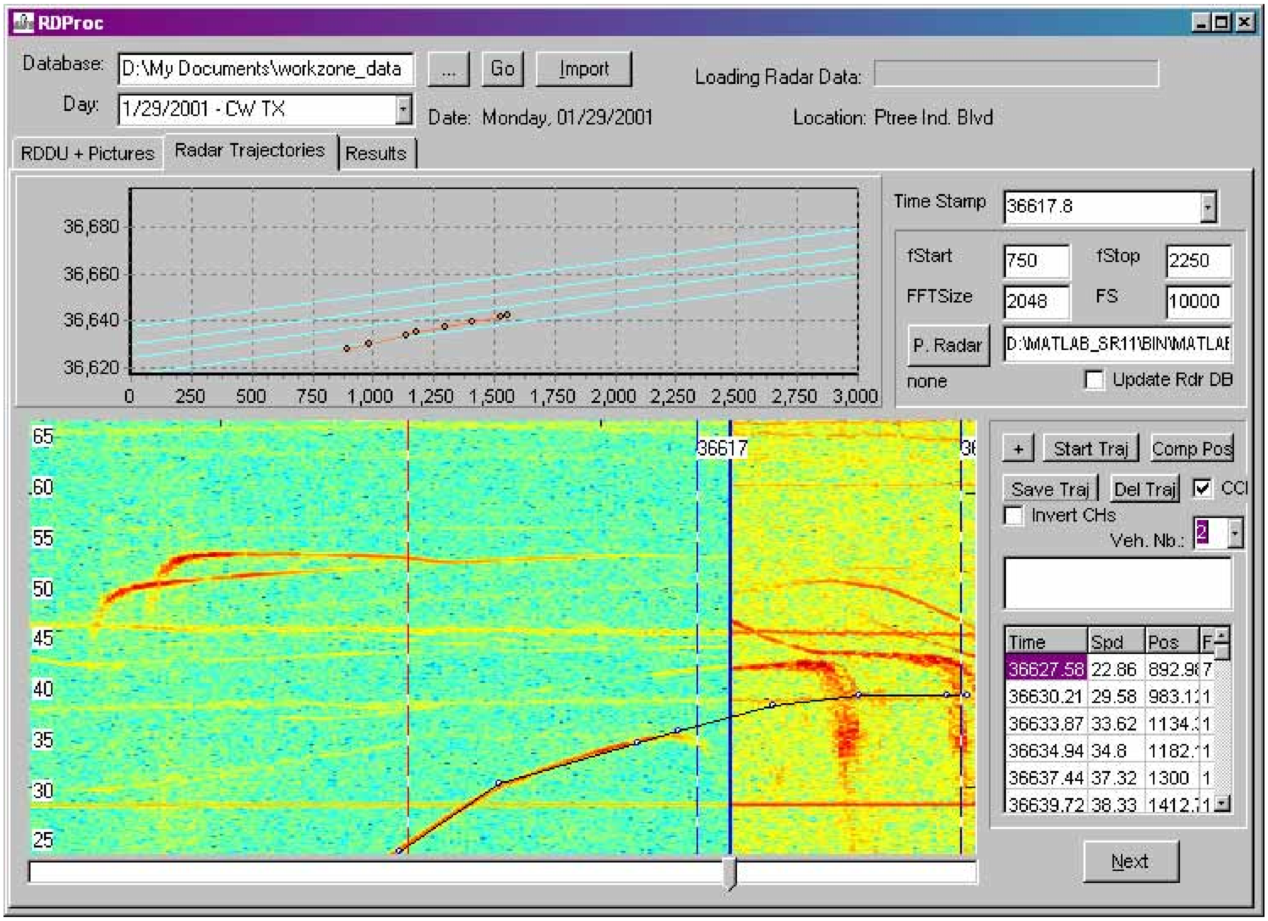



**FIGURE 3 Radar Trajectories Tab of the RDDUProc program.**

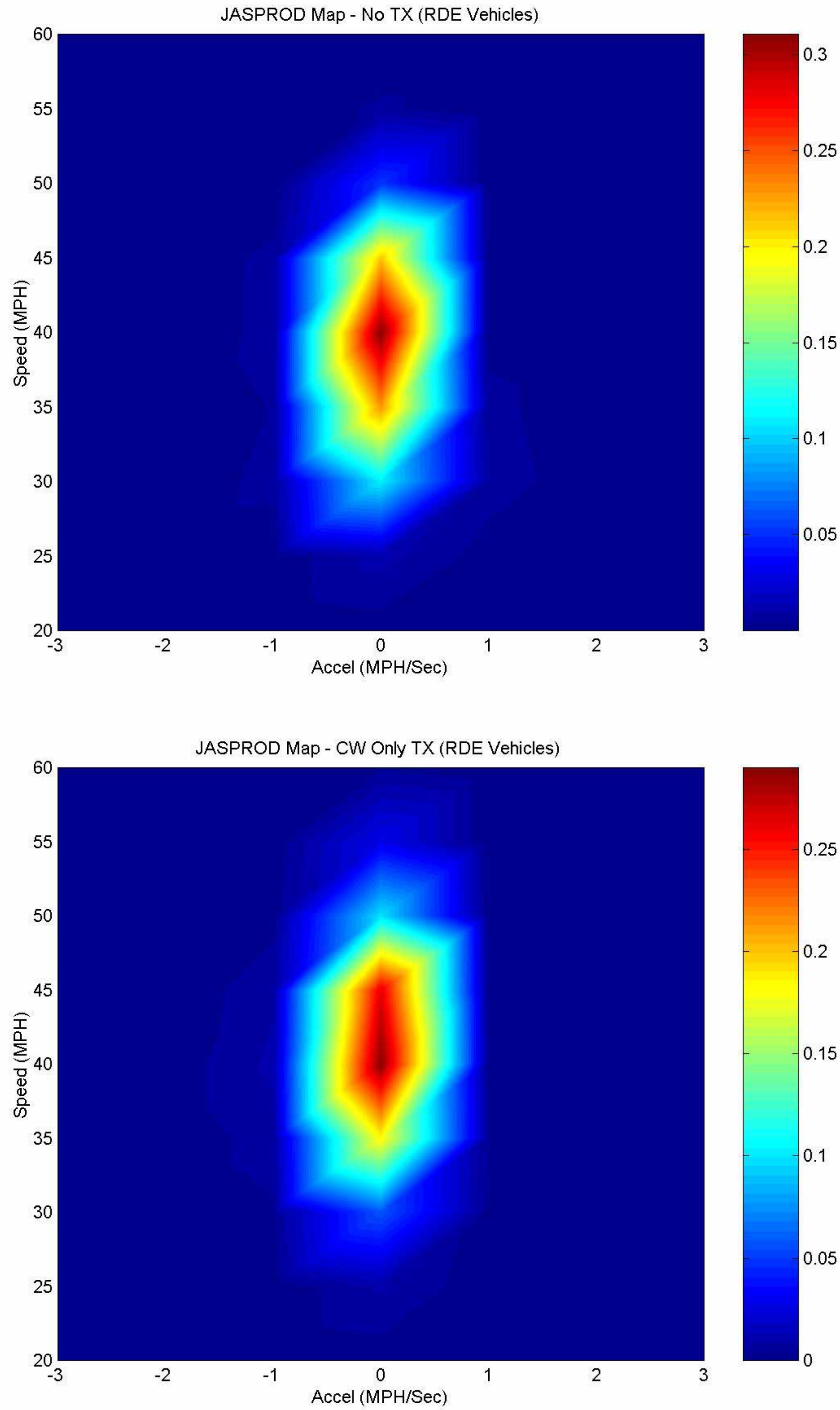



**FIGURE 4 JASPROD Plots for the No TX and CW TX Scenarios.**

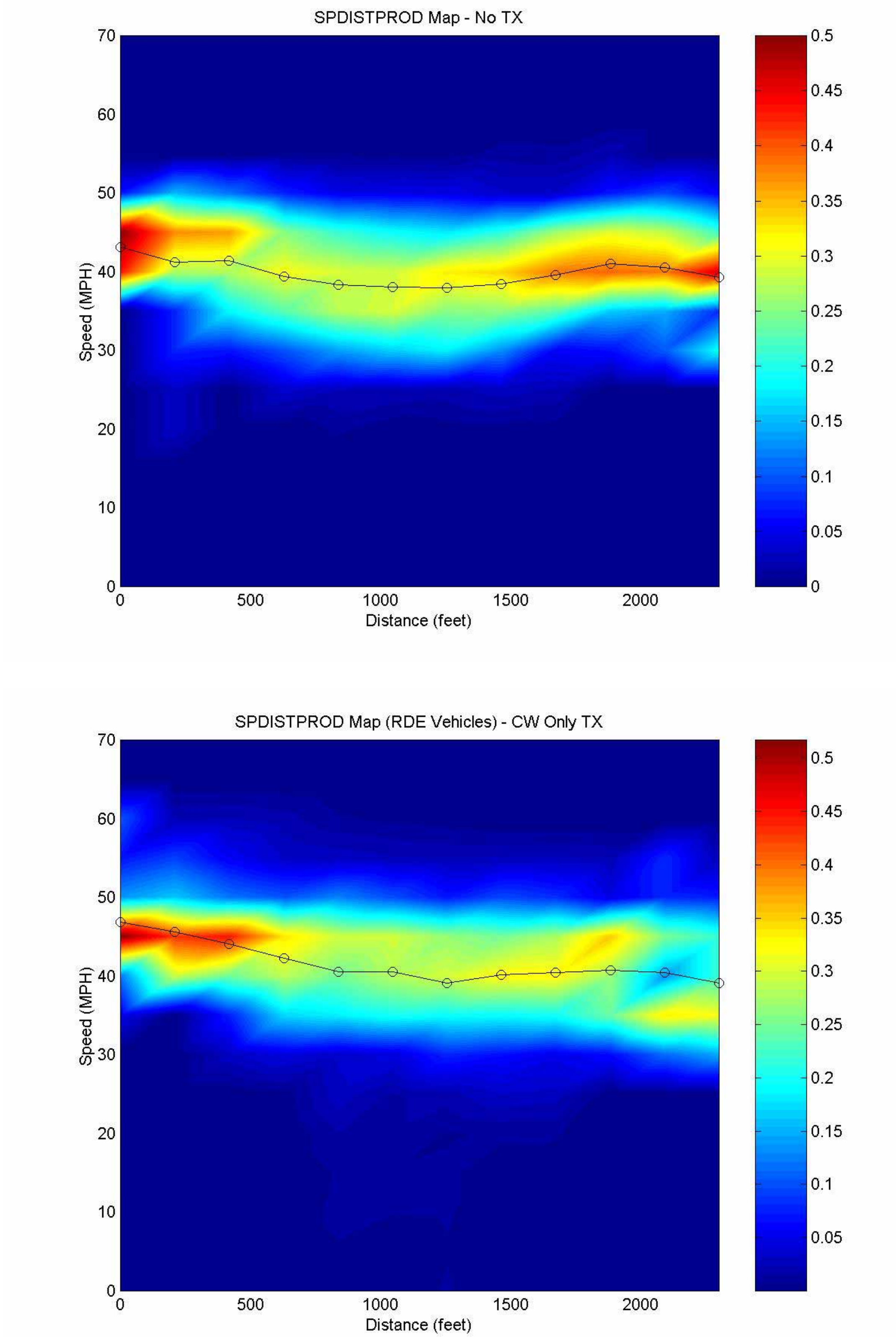
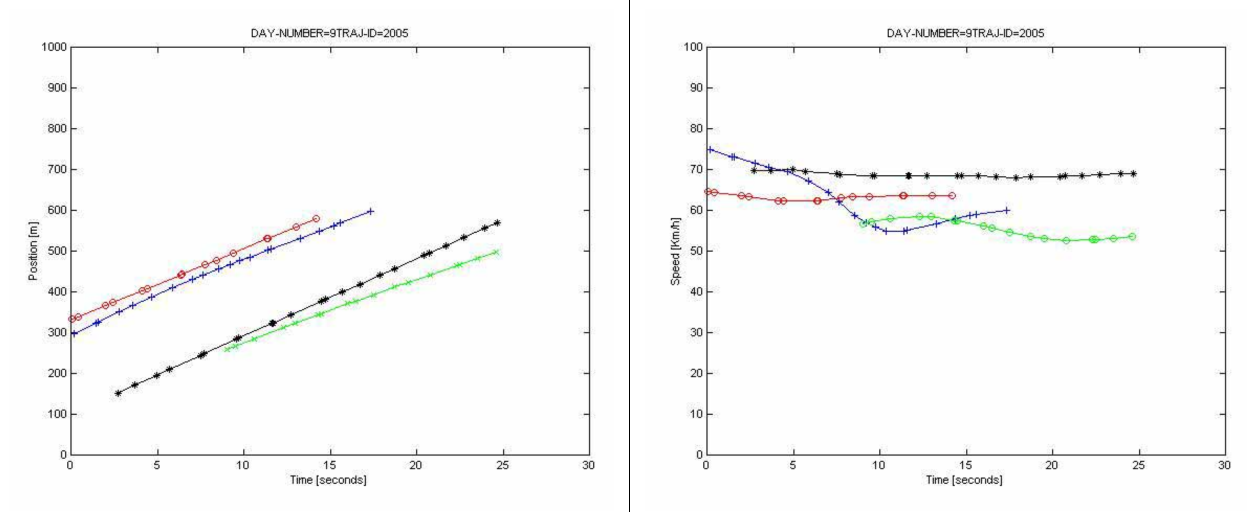



**FIGURE 5 Speed-Distance Probability Density Plots (SPDISTPROD) for the No TX and CW TX Scenarios.**




Vehicle Trajectories

Speed Traces

**FIGURE 6 Example of four vehicles' trajectories and their speeds' trace.**